



# Navy Nuclear-Powered Surface Ships: Background, Issues, and Options for Congress

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## Summary

Some Members of Congress, particularly on the House Armed Services Committee, have expressed interest in expanding the use of nuclear power to a wider array of Navy surface ships, including the Navy's planned CG(X) cruiser. Section 1012 of the FY2008 defense authorization act (H.R. 4986/P.L. 110-181 of January 28, 2008) makes it U.S. policy to construct the major combatant ships of the Navy, including the CG(X), with integrated nuclear power systems, unless the Secretary of Defense submits a notification to Congress that the inclusion of an integrated nuclear power system in a given class of ship is not in the national interest. The Navy has studied nuclear power as a design option for the CG(X), but has not yet announced whether it would prefer to build the CG(X) as a nuclear-powered ship. The Navy's proposed FY2010 budget defers the planned procurement of the first CG(X) from FY2011 (the scheduled date under the FY2009 budget) to a year beyond FY2015, most likely FY2017.

A 2006 Navy study concluded the following, among other things:

- In constant FY2007 dollars, building a Navy surface combatant or amphibious ship with nuclear power rather than conventional power would add roughly \$600 million to \$800 million to its procurement cost.
- The total life-cycle cost of a nuclear-powered medium-size surface combatant would equal that of a conventionally powered medium-size surface combatant if the cost of crude oil averages \$70 per barrel to \$225 per barrel over the life of the ship.
- Nuclear-power should be considered for near-term applications for medium-size surface combatants.
- Compared to conventionally powered ships, nuclear-powered ships have advantages in terms of both time needed to surge to a distant theater of operation for a contingency, and in terms of operational presence (time on station) in the theater of operation.

In assessing whether the CG(X) or other future Navy surface ships should be nuclear-powered, Congress may consider a number of issues, including cost, operational effectiveness, ship construction, ship maintenance and repair, crew training, ports calls and forward homeporting, and environmental impact.

The House Armed Services Committee, in its report (H.Rept. 111-166 of June 18, 2009) on the FY2010 defense authorization bill (H.R. 2647) states that it "remains committed to the direction of section 1012 of the National Defense Authorization Act for Fiscal Year 2008 (Public Law 110-181), which requires the use of an integrated nuclear propulsion system for the CGN(X) [cruiser]." Section 246 of H.R. 2647 would require DOD to submit to the congressional defense committees a study on the use of thorium-liquid fueled nuclear reactors for Navy surface ships.

Section 1012 of the FY2010 defense authorization bill (S. 1390) as reported by the Senate Armed Services Committee (S.Rept. 111-35 of July 2, 2009) would repeal Section 1012 of the FY2008 defense authorization act. The committee's report states: "The committee expects that the Navy will continue to evaluate the integrated nuclear power alternative for any new class of major surface combatants, but would prefer that any Navy requirements analysis not be skewed toward a particular outcome."

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## Introduction and Issue for Congress

Some Members of Congress, particularly on the House Armed Services Committee, have expressed interest in expanding the use of nuclear power to a wider array of Navy surface ships, starting with the Navy's planned CG(X) cruiser. Section 1012 of the FY2008 Defense Authorization Act (H.R. 4986/P.L. 110-181 of January 28, 2008) makes it U.S. policy to construct the major combatant ships of the Navy, including the CG(X), with integrated nuclear power systems, unless the Secretary of Defense submits a notification to Congress that the inclusion of an integrated nuclear power system in a given class of ship is not in the national interest. The Navy has studied nuclear power as a design option for the CG(X), but has not yet announced whether it would prefer to build the CG(X) as a nuclear-powered ship. The Navy's proposed FY2010 budget defers the planned procurement of the first CG(X) from FY2011 (the scheduled date under the FY2009 budget) to a year beyond FY2015, most likely FY2017.

The issue for Congress is whether the CG(X) or other future Navy surface ships should be nuclear-powered. Congress's decisions on this issue could affect, among other things, future Navy capabilities, Navy funding requirements, and the shipbuilding industrial base.

## Background

### Nuclear and Conventional Power for Ships

#### Nuclear and Conventional Power in Brief

Most military ships and large commercial ships are conventionally powered, meaning that they burn a petroleum-based fuel, such as marine diesel, to generate power for propulsion and for operating shipboard equipment. Conventionally powered ships are sometimes called fossil fuel ships.

Some military ships are nuclear-powered, meaning that they use an on-board nuclear reactor to generate power for propulsion and shipboard equipment.<sup>1</sup> Nuclear-powered military ships are operated today by the United States, the United Kingdom, France, Russia, and China. Some other countries, such as India, have expressed interest in, or conducted research and development work on, nuclear-powered military ships. A military ship's use of nuclear power is not an indication of

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<sup>1</sup> U.S. Navy nuclear-powered ships use pressurized water reactors (PWRs) that are fueled with highly enriched uranium. In a PWR, water flowing through the reactor is heated by the nuclear fuel to a high temperature. The water is pressurized (maintained at a high pressure) so that it does not boil as it heats up. A heat exchanger is then used to transfer heat from the radioactive pressurized water to a separate circuit of non-radioactive water. As the non-radioactive water heats up, it turns into steam that is used to power turbines that drive the ship's propellers and generate power for shipboard equipment.

A small number of non-military ships have been built with nuclear power in recent decades, including the U.S.-built commercial cargo ship NS Savannah, three other commercial cargo ships built in Germany, Japan, and the Soviet Union, and several Soviet/Russian-built nuclear-powered icebreakers. The four cargo ships are no longer in service. More recently, the Center for the Commercial Deployment of Transportation Technologies (CCDoTT) of California State University, Long Beach, has examined the potential cost-effectiveness of building a new generation of nuclear-powered commercial cargo ships.

whether it carries nuclear weapons—a nuclear-powered military ship can lack nuclear weapons, and a conventionally powered military ship can be armed with nuclear weapons.

## Nuclear Power for a Surface Combatant

For a surface combatant like a cruiser, using nuclear power rather than conventional power eliminates the need for the ship to periodically refuel during extended operations at sea. Refueling a ship during a long-distance transit can reduce its average transit speed. Refueling a ship that is located in a theater of operations can temporarily reduce its ability to perform its missions. A nuclear-powered surface combatant can steam at sustained high speeds to a distant theater of operations, commence operations in the theater immediately upon arrival, and continue operating in the theater over time, all without a need for refueling.<sup>2</sup>

In contrast, a conventionally powered surface combatant might need to slow down for at-sea refueling at least once during a high-speed, long-distance transit; might need to refuel again upon arriving at the theater of operations; and might need to refuel periodically while in the theater of operations, particularly if the ship's operations in theater require frequent or continuous movement. **Table 1** shows the unrefueled cruising ranges of the Navy's existing conventionally powered cruisers and destroyers at a speed of 20 knots, along with transit distances from major U.S. Navy home ports to potential U.S. Navy operating areas. Navy surface combatants have maximum sustained speeds of more than 30 knots. A speed of 20 knots is a moderately fast long-distance transit speed for a Navy surface combatant. For a higher transit speed, such as 25 knots, the unrefueled cruising ranges would be less than those shown in the table, because the amount of fuel needed to travel a certain distance rises with ship speed, particularly as speeds increase above about 15 knots.

**Table 1. Unrefueled Cruising Ranges and Transit Distances**  
(in nautical miles)

Unrefueled cruising ranges at 20 knots	
Arleigh Burke (DDG-51) class destroyer	4,400 nm
Ticonderoga (CG-47) class cruiser	6,000 nm
Transit distances	
Pearl Harbor, HI, to area east of Taiwan <sup>a,b</sup>	4,283 nm
San Diego, CA, to area east of Taiwan <sup>a,c</sup>	5,933 nm
Pearl Harbor, HI, to Persian Gulf (via Singapore)	~9,500 nm
San Diego, CA, to Persian Gulf (via Singapore) <sup>c</sup>	~11,300 nm
Norfolk to Persian Gulf (via Suez canal)	~8,300 nm

**Sources:** For ship unrefueled cruising ranges: Norman Polmar, *The Naval Institute Guide to the Ships and Aircraft of the U.S. Fleet*, 18<sup>th</sup> ed., Annapolis (MD), 2005. For transit distances to area east of Taiwan: Straight line distances calculated by the “how far is it” calculator, available at <http://www.indo.com/distance/>. (Actual transit distances may be greater due to the possible need for ships to depart from a straight-line course so as to avoid land barriers, remain within port-area shipping channels, etc.) For transit distances to Persian Gulf: Defense Mapping

<sup>2</sup> For an aircraft carrier, the use of nuclear power permits space inside the ship that would have been used for storing ship fuel to be used instead for storing aircraft fuel or other supplies. This lengthens the period of time that a carrier can sustain aircraft operations before needing to take on fuel or other supplies.

Agency, *Distances Between Ports* (Pub. 151), 7<sup>th</sup> ed., 1993, with distances shown for reaching a position roughly in the center of the Persian Gulf.

- a. Area east of Taiwan defined as a position in the sea at 24°N, 124°E, which is roughly 130 nautical miles east of Taiwan.
- b. Distance from Pearl Harbor calculated from Honolulu, which is about 6 nautical miles southeast of Pearl Harbor.
- c. For transit distances from the Navy home port at Everett, WA, north of Seattle, rather than from San Diego, subtract about 700 nm.

During extended operations at sea, a nuclear-powered surface combatant, like a conventionally powered one, might need to be resupplied with food, weapons (if sufficient numbers are expended in combat), and other supplies. These resupply operations can temporarily reduce the ship's ability to perform its missions.

## **U.S. Navy Nuclear-Powered Ships**

### **Naval Nuclear Propulsion Program**

The Navy's nuclear propulsion program began in 1948. The Navy's first nuclear-powered ship, the submarine *Nautilus* (SSN-571), was commissioned into service on September 30, 1954, and went to sea for the first time on January 17, 1955. The Navy's first nuclear-powered surface ships, the cruiser *Long Beach* (CGN-9) and the aircraft carrier *Enterprise* (CVN-65), were commissioned into service on September 9, 1961, and November 25, 1961, respectively.

The Navy's nuclear propulsion program is overseen and directed by an office called Naval Reactors (NR), which exists simultaneously as a part of both the Navy (where it forms a part of the Naval Sea Systems Command) and the Department of Energy (where it forms a part of the National Nuclear Security Administration). NR has broad, cradle-to-grave responsibility for the Navy's nuclear-propulsion program. This responsibility is set forth in Executive Order 12344 of February 1, 1982, the text of which was effectively incorporated into the U.S. Code (at 50 USC 2511)<sup>3</sup> by Section 1634 of the FY1985 defense authorization act (H.R. 5167/P.L. 98-525 of October 19, 1984) and again by section 3216 of the FY2000 defense authorization act (S. 1059/P.L. 106-65 of October 5, 1999). NR has established a reputation for maintaining very high safety standards for engineering and operating Navy nuclear power plants.

The first director of NR was Admiral Hyman Rickover, who served in the position from 1948 until 1982. Rickover is sometimes referred to as the father of the nuclear Navy. The current director is Admiral Kirkland Donald, who became director in November 2004. He is the fifth person to hold the position.

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<sup>3</sup> See also 42 USC 7158.

## Current Navy Nuclear-Powered Ships

As of the end of FY2007, the Navy's nuclear-powered fleet included all 71 of its submarines and 10 of its 11 aircraft carriers. The Navy's combat submarine force has been entirely nuclear-powered since 1990.<sup>4</sup> The Navy's carrier force is to become entirely nuclear powered in 2008.<sup>5</sup>

## Earlier Navy Nuclear-Powered Cruisers

In addition to nuclear-powered submarines and nuclear-powered carriers, the Navy in the past built and operated nine nuclear-powered cruisers (CGNs). The nine ships, which are shown in **Table 2**, include three one-of-a-kind designs (CGNs 9, 25, and 35) followed by the two-ship California (CGN-36) class and the four-ship Virginia (CGN-38) class.

The nuclear-powered cruisers shown in **Table 2** were procured to provide nuclear-powered escorts for the Navy's nuclear-powered carriers. Procurement of nuclear-powered cruisers was halted after FY1975 largely due to a desire to constrain the procurement costs of future cruisers. In deciding in the late 1970s on the design for the new cruiser that would carry the Aegis defense system, two nuclear-powered Aegis-equipped options—a 17,200-ton nuclear-powered strike cruiser (CSGN) and a 12,100-ton derivative of the CGN-38 class design—were rejected in favor of a third option of placing the Aegis system onto the smaller, conventionally powered hull originally developed for the Spruance (DD-963) class destroyer. The CSGN was estimated to have a procurement cost twice that of the DD-963-based option, while the CGN-42 was estimated to have a procurement cost 30%-50% greater than that of the DD-963-based option. The DD-963-based option became the 9,500-ton Ticonderoga (CG-47) class Aegis cruiser. The first Aegis cruiser was procured in FY1978.

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<sup>4</sup> The Navy's final three non-nuclear-powered combat submarines were procured in FY1956, entered service in 1959, retired in 1988-1990. A non-nuclear-powered, non-combat auxiliary research submarine, the Dolphin (AGSS-555), was procured in FY1961, entered service in 1968, and retired in January 2007.

<sup>5</sup> The one conventionally powered carrier in service as of the end of FY2007—the Kitty Hawk (CV-63)—was procured in FY1956, entered service in 1961, and is scheduled to be retired in 2008.

**Table 2. Earlier Navy Nuclear-Powered Cruisers**

Hull number	Name	Builder	Displacement (tons)	Procured	Entered service	Decommissioned
CGN-9	Long Beach	Bethlehem <sup>a</sup>	17,100	FY57	1961	1995
CGN-25	Bainbridge	Bethlehem <sup>a</sup>	8,580	FY59	1962	1996
CGN-35	Truxtun	New York <sup>b</sup>	8,800	FY62	1967	1995
CGN-36	California	NGNN <sup>c</sup>	10,530	FY67	1974	1999
CGN-37	South Carolina	NGNN <sup>c</sup>	10,530	FY68	1975	1999
CGN-38	Virginia	NGNN <sup>c</sup>	11,300	FY70	1976	1994
CGN-39	Texas	NGNN <sup>c</sup>	11,300	FY71	1977	1993
CGN-40	Mississippi	NGNN <sup>c</sup>	11,300	FY72	1978	1997
CGN-41	Arkansas	NGNN <sup>c</sup>	11,300	FY75	1980	1998

**Source:** Prepared by CRS based on Navy data and Norman Polmar, *The Ships and Aircraft of the U.S. Fleet*.

a. Bethlehem Steel, Quincy, MA.

b. New York Shipbuilding, Camden, NJ.

c. Newport News Shipbuilding, now known as Northrop Grumman Newport News (NGNN).

## Initial Fuel Core Included in Procurement Cost

The initial fuel core for a Navy nuclear-powered ship is installed during the construction of the ship. The procurement cost of the fuel core is included in the total procurement cost of the ship, which is funded in the Navy's shipbuilding budget, known formally as the Shipbuilding and Conversion, Navy (SCN) appropriation account. In constant FY2007 dollars, the initial fuel core for a Virginia (SSN-774) class submarine costs about \$170 million; the initial fuel cores for an aircraft carrier (which uses two reactors and therefore has two fuel cores) have a combined cost of about \$660 million.<sup>6</sup>

The procurement cost of a conventionally powered Navy ship, in contrast, does not include the cost of petroleum-based fuel needed to operate the ship, and this fuel is procured largely through the Operation and Maintenance, Navy (OMN) appropriation account.

## CG(X) Cruiser Program<sup>7</sup>

### The Program in General

The CG(X) cruiser is the Navy's planned replacement for its 22 Aegis cruisers, which are projected to reach retirement age between 2021 and 2029. The Navy's planned 313-ship fleet

<sup>6</sup> Source: Telephone conversation with Naval Reactors, March 8, 2007. Naval Reactor states that the cost figure of about \$660 million for an aircraft carrier (\$330 million for each of two fuel cores) applies to both existing Nimitz (CVN-68) class carriers and the new Gerald R. Ford (CVN-78) class carrier (also known as the CVN-21 class).

<sup>7</sup> For more on the CG(X) program, see CRS Report RL34179, *Navy CG(X) Cruiser Program: Background, Oversight Issues, and Options for Congress*, by Ronald O'Rourke.

calls for a total of 19 CG(X)s.<sup>8</sup> The FY2009-FY2013 Future Years Defense Plan (FYDP) called for procuring the first CG(X) in FY2011, but the Navy's proposed FY2010 budget defers the planned procurement of the first CG(X) from FY2011 to a year beyond FY2015, most likely FY2017.

The Navy is currently assessing CG(X) design options in a large study called the CG(X) Analysis of Alternatives (AOA), known more formally as the Maritime Air and Missile Defense of Joint Forces (MAMDJF) AOA. The Navy has stated that it wants to equip the CG(X) with a combat system featuring a powerful radar capable of supporting ballistic missile defense (BMD) operations.<sup>9</sup> The Navy has testified that this combat system is to have a power output of 30 or 31 megawatts, which is several times the power output of the combat system on the Navy's existing cruisers and destroyers.<sup>10</sup> This suggests that in terms of power used for combat system operations, the CG(X) might use substantially more energy over the course of its life than the Navy's existing cruisers and destroyers. As discussed later in this report, a ship's life-cycle energy use is a factor in evaluating the economic competitiveness of nuclear power compared to conventional power.

### **Reactor Plant for a Nuclear-Powered CG(X)**

The Navy testified in 2007 that in the Navy's 2006 study on alternative ship propulsion systems (see section below), the notional medium-sized surface combatant in the study (which the study defined as a ship with a displacement between 21,000 metric tons and 26,000 metric tons) used a modified version of one-half of the reactor plant that the Navy has developed for its new Gerald R. Ford (CVN-78) class aircraft carriers, also called the CVN-21 class.<sup>11</sup> The Ford-class reactor plant, like the reactor plant on the Navy's existing Nimitz (CVN-68) class aircraft carriers, is a twin reactor plant that includes two nuclear reactors.<sup>12</sup> The medium-sized surface combatant employed a modified version of one-half of this plant, with a single reactor.

This suggests that if the CG(X) is a ship with a displacement of 21,000 or more metric tons, its reactor plant could be a modified version of one-half of the Ford-class reactor plant. This approach would minimize the time and cost of developing a reactor plant for a nuclear-powered CG(X). In the Ford class, the initial nuclear fuel cores in the two reactors are to be sufficient to power the ship for one-half of its expected life of 40 to 50 years. In a nuclear-powered CG(X), the Navy has said, the initial fuel core in the single reactor would be sufficient to power the ship for its entire expected life of 30 to 35 years. Since the two fuel cores for an aircraft carrier cost about \$660 million in constant FY2007 dollars (see previous section on initial fuel cores), the cost of a single fuel core for a CG(X) might be about \$330 million in constant FY2007 dollars.

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<sup>8</sup> For more on the Navy's 313-ship plan, see CRS Report RL32665, *Navy Force Structure and Shipbuilding Plans: Background and Issues for Congress*, by Ronald O'Rourke.

<sup>9</sup> For more on Navy BMD programs, see CRS Report RL33745, *Sea-Based Ballistic Missile Defense—Background and Issues for Congress*, by Ronald O'Rourke.

<sup>10</sup> Source: Testimony of Navy officials to the Seapower and Expeditionary Forces Subcommittee of the House Armed Services Committee, March 1, 2007.

<sup>11</sup> Source: Testimony of Navy officials to the Seapower and Expeditionary Forces Subcommittee of the House Armed Services Committee, March 1, 2007.

<sup>12</sup> For more on the CVN-21 program, see CRS Report RS20643, *Navy Ford (CVN-78) Class Aircraft Carrier Program: Background and Issues for Congress*, by Ronald O'Rourke.

## Construction Shipyards

### Nuclear-Capable Shipyards

Two U.S. shipyards are currently certified to build nuclear-powered ships—Northrop Grumman Newport News (NGNN) of Newport News, VA, and General Dynamics’ Electric Boat Division (GD/EB) of Groton, CT, and Quonset Point, RI. NGNN can build nuclear-powered surface ships and nuclear-powered submarines. GD/EB can build nuclear-powered submarines. NGNN has built all the Navy’s nuclear-powered aircraft carriers. NGNN also built the final six nuclear-powered cruisers shown in **Table 2**. NGNN and GD/EB together have built every Navy nuclear-powered submarine procured since FY1969.

Although NGNN and GD/EB are the only U.S. shipyards that currently build nuclear-powered ships for the Navy, five other U.S. shipyards once did so as well.<sup>13</sup> These five yards built 44 of the 107 nuclear-powered submarines that were procured for the Navy through FY1968. Two of these five yards built the first three nuclear-powered cruisers shown in **Table 2**.

### Surface Combatant Shipyards

All cruisers and destroyers procured for the Navy since FY1978 have been built at two shipyards—General Dynamics’ Bath Iron Works (GD/BIW) of Bath, ME, and the Ingalls shipyard at Pascagoula, MS, that now forms part of Northrop Grumman Ship Systems (NGSS). GD/BIW has never built nuclear-powered ships. Ingalls is one of the five U.S. yards other than NGNN and GD/EB that once built nuclear-powered ships. Ingalls built 12 nuclear-powered submarines, the last being the *Parche* (SSN-683), which was procured in FY1968, entered service in 1974, and retired in 2005.<sup>14</sup> Ingalls also overhauled or refueled 11 nuclear-powered submarines. Ingalls’ nuclear facility was decommissioned in 1980, and NGSS is not certified to build nuclear-powered ships.<sup>15</sup>

## Recent Navy Studies for Congress

The Navy has conducted two recent studies for Congress on the potential cost-effectiveness of expanding the use of nuclear power to a wider array of surface ships. These studies are the 2005 Naval Reactors quick look analysis, and the more comprehensive and detailed 2006 Navy alternative propulsion study. Each of these is discussed below.

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<sup>13</sup> The five yards are the Portsmouth Naval Shipyard of Kittery, ME; the Mare Island Naval Shipyard of Mare Island, CA; the Ingalls shipyard of Pascagoula, MS, that now forms part of Northrop Grumman Ship Systems; Bethlehem Steel of Quincy, MA (which became a part of General Dynamics); and New York Shipbuilding of Camden, NJ.

<sup>14</sup> Ingalls built its nuclear-powered submarines at its older East Bank facility. Ingalls’ newer West Bank facility has been used for building conventionally powered surface ships, principally surface combatants and large-deck amphibious ships.

<sup>15</sup> In addition to building 12 nuclear-powered submarines, Northrop Grumman states that Ingalls’ facilities “allowed Ingalls to participate in submarine overhaul and refueling. By the time the shipyard’s nuclear facility was decommissioned in 1980, 11 U.S. Navy attack submarines had been overhauled and/or refueled at Ingalls.” Source: Northrop Grumman chronological perspective on Northrop Grumman Ship Systems, at <http://www.ss.northropgrumman.com/company/chronological.html>.

## 2005 Naval Reactors Quick Look Analysis

The 2005 NR quick look analysis was conducted at the request of Representative Roscoe Bartlett, who was then chairman of the Projection Forces Subcommittee of the House Armed Services Committee (since renamed the Seapower and Expeditionary Forces Subcommittee). The analysis concluded that the total life-cycle cost (meaning the sum of procurement cost, life-cycle operating and support cost, and post-retirement disposal cost) of a nuclear-powered version of a large-deck (LHA-type) amphibious assault ship would equal that of a conventionally powered version of such a ship if the cost of crude oil over the life of the ship averaged about \$70 per barrel. The study concluded that the total life-cycle cost of a nuclear-powered surface combatant would equal that of a conventionally powered version if the cost of crude oil over the life of the ship averaged about \$178 per barrel. This kind of calculation is called a life-cycle cost break-even analysis. The study noted but did not attempt to quantify the mobility-related operational advantages of nuclear propulsion for a surface ship.<sup>16</sup>

## 2006 Navy Alternative Propulsion Study

The more comprehensive and detailed 2006 Navy alternative propulsion study was conducted in response to Section 130 of the FY2006 defense authorization act (H.R. 1815, P.L. 109-163 of January 6, 2006), which called for such a study (see **Appendix**). The study reached a number of conclusions, including the following:

- In constant FY2007 dollars, building a Navy surface combatant or amphibious ship with nuclear power rather than conventional power would add roughly \$600 million to \$800 million to its procurement cost.
  - For a small surface combatant, the procurement-cost increase was about \$600 million.
  - For a medium-size combatant (defined as a ship with a displacement between 21,000 metric tons and 26,000 metric tons), the increase was about \$600 million to about \$700 million.
  - For an amphibious ship, the increase was about \$800 million.<sup>17</sup>
- Although nuclear-powered ships have higher procurement costs than conventionally powered ships, they have lower operating and support costs when fuel costs are taken into account.
- A ship's operational tempo and resulting level of energy use significantly influences the life-cycle cost break-even analysis. The higher the operational tempo and resulting level of energy use assumed for the ship, lower the cost of

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<sup>16</sup> U.S. Naval Nuclear Propulsion Program, briefing entitled "Nuclear and Fossil Fuel Powered Surface Ships, Quick Look Analysis," presented to CRS on March 22, 2006. The analysis concluded that total life-cycle costs for nuclear-powered versions of large-deck aircraft carriers, LHA-type amphibious assault ships and surface combatants would equal those of conventionally powered versions when the price of diesel fuel marine (DFM) delivered to the Navy reached \$55, \$80, and \$205 per barrel, respectively. Since the cost of DFM delivered to the Navy was calculated to be roughly 15% greater than that of crude oil, these figures corresponded to break-even crude-oil costs of about \$48, \$70, and \$178 per barrel, respectively.

<sup>17</sup> In each case, the cost increase is for the fifth ship in a class being built at two shipyards.

- crude oil needed to break even on a life-cycle cost basis, and the more competitive nuclear power becomes in terms of total life-cycle cost.
- The newly calculated life-cycle cost break-even cost-ranges, which supercede the break-even cost figures from the 2005 NR quick look analysis, are as follows:
    - \$210 per barrel to \$670 per barrel for a small surface combatant;
    - \$70 per barrel to \$225 per barrel for a medium-size surface combatant; and
    - \$210 per barrel to \$290 per barrel for an amphibious ship. In each case, the lower dollar figure is for a high ship operating tempo, and the higher dollar figure is for a low ship operating tempo.
  - At a crude oil cost of \$74.15 per barrel (which was a market price at certain points in 2006), the life-cycle cost premium of nuclear power is:
    - 17% to 37% for a small surface combatant;
    - 0% to 10% for a medium sized surface combatant; and
    - 7% to 8% for an amphibious ship.
  - The life-cycle cost break-even analysis indicates that nuclear-power should be considered for near-term applications for medium-size surface combatants, and that life-cycle cost will not drive the selection of nuclear power for small surface combatants or amphibious ships. A nuclear-powered medium-size surface combatant is the most likely of the three ship types studied to prove economical, depending on the operating tempo that the ship actually experiences over its lifetime.
  - Compared to conventionally powered ships, nuclear-powered ships have advantages in terms of both time needed to surge to a distant theater of operation for a contingency, and operational presence (time on station) in the theater of operation.<sup>18</sup>

## Potential Issues for Congress

In assessing whether the CG(X) or other future Navy surface ships should be nuclear-powered, Congress may consider a number of issues, including cost, operational effectiveness, ship construction, ship maintenance and repair, crew training, ports calls and forward homeporting, and environmental impact. Each of these is discussed below.

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<sup>18</sup> Source: Statement of The Honorable Dr. Delores M. Etter, Assistant Secretary of the Navy (Research, Development and Acquisition), et al., Before the Seapower and Expeditionary Forces Subcommittee of the House Armed Services Committee on Integrated Nuclear Power Systems for Future Naval Surface Combatants, March 1, 2007, pp. 4-5.

## Cost

### Development and Design Cost

The cost calculations presented in the 2006 Navy alternative propulsion study do not include the additional up-front design and development costs, if any, for a nuclear-powered surface ship. As discussed in the “Background” section, if the CG(X) displaces 21,000 or more metric tons, the Navy could have the option of fitting the CG(X) with a modified version of one-half of the Ford (CVN-78) class aircraft carrier nuclear power plant. This could minimize the up-front development cost of the CG(X) nuclear power plant. If the CG(X) is not large enough to accommodate a modified version of one-half of the Ford-class plant, then a new nuclear plant would need to be designed for the CG(X). Although this new plant could use components common to the Ford-class plant or other existing Navy nuclear plants, the cost of developing this new plant would likely be greater than the cost of modifying the Ford-class plant design.

### Procurement Cost

#### *For the CG(X)*

As mentioned in the “Background” section, the Navy has stated a preference for basing the design of the CG(X) on the design of its new DDG-1000 class destroyer, which is a conventionally powered ship. This approach could result in a conventionally powered CG(X) design with a procurement cost similar to that of the DDG-1000. If a conventionally powered CG(X) were to have a procurement cost equal to that of the DDG-1000 design, then a nuclear-powered CG(X) might cost roughly 32% to 37% more than a conventionally powered CG(X).<sup>19</sup> If a conventionally powered CG(X) were to have a procurement cost greater than that of the DDG-1000, then the percentage procurement cost premium for nuclear power for the CG(X) would be less than 32% to 37%. The 2006 Navy study states that for a medium-size surface combatant that is larger than the DDG-1000, an additional cost of about \$600 million to \$700 million would equate to a procurement cost increase of about 22%.

If building a Navy surface combatant or amphibious ship with nuclear power rather than conventional power would add roughly \$600 million to \$700 million to its procurement cost, then procuring one or two nuclear-powered CG(X)s per year, as called for in the Navy’s 30-year shipbuilding plan, would cost roughly \$600 million to \$1,400 million more per year than procuring one or two conventionally powered CG(X)s per year, and procuring a force of 19 nuclear-powered CG(X)s would cost roughly \$11.4 billion to \$13.3 billion more than procuring a force of 19 conventionally powered CG(X)s. For purposes of comparison, the Navy has requested a total of \$13.7 billion for the SCN account for FY2008.

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<sup>19</sup> The Navy in 2007 estimated that follow-on DDG-1000 destroyers would cost an average of about \$1.9 billion each to procure in constant FY2007 dollars. (This figure was based on the then-year costs for the third through seventh ships in the DDG-1000 class, which the Navy wants to procure in FY2009-FY2013. These costs were converted into constant FY2007 dollars using a January 2007 Navy shipbuilding deflator. The deflator was provided by the Navy to the Congressional Budget Office, which forwarded it to CRS.) Increasing a ship’s procurement cost from about \$1.9 billion to \$2.5 billion or \$2.6 billion (i.e., increasing it by \$600 million to \$700 million) equates to an increase of 32% to 37%.

### ***For Submarines and Aircraft Carriers***

The Navy in 2007 estimated that building the CG(X) or other future Navy surface ships with nuclear power could reduce the production cost of nuclear-propulsion components for submarines and aircraft carriers by 5% to 9%, depending on the number of nuclear-powered surface ships that are built.<sup>20</sup> Building one nuclear-powered cruiser every two years, the Navy has testified, might reduce nuclear-propulsion component costs by about 7%. In a steady-state production environment, the Navy testified in 2007, the savings might equate to about \$115 million for each aircraft carrier, and about \$35 million for each submarine. The Navy stated that this “is probably the most optimistic estimate.”<sup>21</sup> The Navy states that these savings were not included in the cost calculations presented in the 2006 Navy study.

BWXT, a principal maker of nuclear-propulsion components for Navy ships, estimated in 2007 that increasing Virginia-class submarine procurement from one boat per year to two boats per year would reduce the cost of nuclear propulsion components 9% for submarines and 8% for aircraft carriers, and that “Adding a nuclear[-powered] cruiser or [nuclear-powered] large-deck amphibious ship would significantly drive down nuclear power plant costs across the fleet, even beyond the savings associated with the second Virginia-class [submarine per year].”<sup>22</sup>

### **Total Life-Cycle Cost**

As suggested by the 2006 Navy study, the total-life-cycle cost break-even analysis can be affected by projections of future oil prices and ship operating tempo.

### ***Future Oil Prices***

Views on potential future oil prices vary.<sup>23</sup> Some supporters of using nuclear power for the CG(X) and other future Navy surface ships, such as Representatives Gene Taylor and Roscoe Bartlett, the chairman and ranking member, respectively, of the Seapower and Expeditionary Forces Subcommittee of the House Armed Services Committee, believe that oil in coming decades may become increasingly expensive, or that guaranteed access to oil may become more problematic, and that this is a central reason for making the CG(X) or other future Navy surface ships nuclear-powered.<sup>24</sup>

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<sup>20</sup> Statement of Admiral Kirkland H. Donald, U.S. Navy, Director, Naval Nuclear Propulsion Program, Before the House Armed Services Committee Seapower and Expeditionary Forces Subcommittee on Nuclear Propulsion For Surface Ships, 1 March 2007, p. 13.

<sup>21</sup> Spoken testimony of Admiral Kirkland Donald before the Seapower and Expeditionary Forces Subcommittee of the House Armed Services Committee, March 1, 2007.

<sup>22</sup> Testimony of Winfred Nash, President, BWXT, Nuclear Operations Division, Before the Subcommittee on Seapower and Expeditionary Forces of the House Armed Service Committee [on Submarine Force Structure and Acquisition Policy], March 8, 2007, pp. 2 and 4.

<sup>23</sup> For a standard U.S. government projection of future oil prices, assuming current policy remains in place, see the Energy Information Administration’s Annual Energy Outlook, at <http://www.eia.doe.gov/oiaf/aeo/index.html>.

<sup>24</sup> See, for example, the remarks of Representative Taylor at the hearing of the Seapower and Expeditionary Forces Subcommittee of the House Armed Services Committee, March 1, 2007.

### ***Ship Operating Tempo***

A ship's average lifetime operating tempo can be affected by the number of wars, crises, and other contingency operations that it participates in over its lifetime, because such events can involve operating tempos that are higher than those of "normal" day-to-day operations. Ship operating tempo can also be affected by the size of the Navy. The lower the number of ships in the Navy, for example, the higher the operating tempo each a ship might be required to sustain for the fleet to accomplish a given set of missions.

### ***CG(X) vs. Medium-Size Surface Combatant***

If the CG(X) is based on the hull design of the 14,500-ton DDG-1000 destroyer, which is the Navy's stated preference, then the CG(X) may be smaller the 21,000- to 26,000-ton medium-size surface combatant in the 2006 Navy study. What difference that might create between the CG(X) and the medium-size surface combatant in terms of life-cycle energy use, and thus life-cycle cost break-even range, is not clear. The Navy has testified that the medium sized surface combatant in the 2006 study was modeled with a radar requiring 30 or 31 megawatts of power, like the radar the Navy wants to install on the CG(X).<sup>25</sup>

## **Operational Effectiveness**

### **Operational Value of Increased Ship Mobility**

What is the operational value of increased ship mobility? How much better can a ship perform its missions as a result of this increased mobility? And is there some way to translate the mobility advantages of nuclear power into dollar terms? One potential way to translate the value of increased ship mobility into dollar terms would be to determine how much aggregate capability a force of 19 conventionally powered CG(X)s would have for surging to distant theaters and for maintaining on-station presence in theater, then determine how many nuclear-powered CG(X)s would be required to provide the same aggregate capability, and then compare the total cost of the 19 conventionally powered CG(X)s to the total cost of the nuclear-powered CG(X) force.

### **Potential Other Operational Advantages of Nuclear Power**

Are there operational advantages of nuclear power for a surface ship other than increased ship mobility? One possibility concerns ship detectability. A nuclear-powered ship does not require an exhaust stack as part of its deckhouse, and does not emit hot exhaust gases. Other things held equal, this might make a nuclear-powered surface ship less detectible than a conventionally powered ship, particularly to infrared sensors. This possible advantage for the nuclear-powered ship might be either offset or reinforced by possible differences between the nuclear-powered ship and the conventionally powered ship in other areas, such as the temperature of the engine compartment (which again might affect infrared detectability) or the level of machinery noise (which might affect acoustic detectability).

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<sup>25</sup> Source: Testimony of Navy officials to the Seapower and Expeditionary Forces Subcommittee of the House Armed Services Committee, March 1, 2007.

Some supporters of building future Navy surface ships with nuclear power have argued that an additional operational advantage of nuclear power for surface ships would be to reduce the Navy's dependence on its relatively small force of refueling oilers, and thus the potential impact on fleet operations of an enemy attack on those oilers. The Navy acknowledges that potential attacks on oilers are a concern, but argues that the fleet's vulnerability to such attacks is recognized and that oilers consequently are treated as high-value ships in terms of measures taken to protect them from attack.<sup>26</sup>

Another potential advantage of nuclear power postulated by some observers is that a nuclear-powered ship can use its reactor to provide electrical power for use ashore for extended periods of time, particularly to help localities that are experiencing brownouts during peak use periods or whose access to electrical power from the grid has been disrupted by a significant natural disaster or terrorist attack. The Navy has stated that the CG(X) is to have a total power-generating capacity of about 80 megawatts (MW). Some portion of that would be needed to operate the reactor plant itself and other essential equipment aboard the ship. Much of the rest might be available for transfer off the ship. For purposes of comparison, a typical U.S. commercial power plant might have a capacity of 300 MW to 1000 MW. A single megawatt can be enough to meet the needs of several hundred U.S. homes, depending on the region of the country and other factors.<sup>27</sup>

Skeptics of the idea of using nuclear-powered ships to generate electrical power for use ashore could argue that if the local transmission system has been disrupted, the ship's generation capacity may be of limited use in restoring electric power. If the local transmission system is intact, they could argue, onshore infrastructure would be required to transmit the ship's power into the local system. The military or a local utility, they could argue, would likely bear the cost for this infrastructure, which would be used only on a sporadic basis. Skeptics could argue that a Navy ship would be helpful only if the power emergency lasts longer than the time it would take for the ship to reach the connection point. If the nearest available Navy ship is several steaming days away from the connection point when the power emergency occurs, they could argue, the ship might not be able arrive before local power is partially or fully restored. Skeptics could argue that critical facilities in the area of the power emergency, such as hospitals, would likely be equipped with emergency back-up diesel generators to respond to short-term loss of power.<sup>28</sup>

## Ship Construction

### Shipyards

Another potential issue for Congress to consider in weighing whether the CG(X) or other future Navy surface ships should be nuclear-powered concerns the shipyards that would be used to build the ships. There are at least three potential approaches for building nuclear-powered CG(X)s:

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<sup>26</sup> Spoken testimony of Vice Admiral Jonathan Greenert before the Seapower and Expeditionary Forces Subcommittee of the House Armed Services Committee, March 1, 2007.

<sup>27</sup> See, for example, the discussion of the issue at <http://www.utilipoint.com/issuealert/print.asp?id=1728>.)

<sup>28</sup> For examples of articles discussing the idea of using nuclear-powered ships to generate electrical power for use ashore, see Jose Femenia, "Nuclear Ships Can Help Meet U.S. Electrical Needs," *U.S. Naval Institute Proceedings*, August 2004: 78-80; and Linda de France, "Using Navy Nuclear Reactors To Help Power California Not Worth Effort," *Aerospace Daily*, May 4, 2001.

- Build them at NGNN, with GD/EB possibly contributing to the construction of the ships' nuclear portions.
- Certify NGSS and/or GD/BIW to build nuclear-powered ships, and then build the CG(X)s at those yards.
- Build the nuclear portions of the CG(X)s at NGNN and/or GD/EB, the non-nuclear portions at NGSS and/or GD/BIW, and perform final assembly, integration, and test work for the ships at either
  - NGNN and/or GD/EB, or
  - NGSS and/or GD/BIW.

These options have significant potential implications for workloads and employment levels at each of these shipyards.

On the question of what would be needed to certify NGSS and/or GD/BIW to build nuclear-powered ships, the director of NR testified that

Just the basics of what it takes to have a nuclear-certified yard, to build one from scratch, or even if one existed once upon a time as it did at Pascagoula, and we shut it down, first and foremost you have to have the facilities to do that. What that includes, and I have just some notes here, but such things as you have to have the docks and the dry-docks and the pier capability to support nuclear ships, whatever that would entail. You would have to have lifting and handling equipment, cranes, that type of thing; construction facilities to build the special nuclear components, and to store those components and protect them in the way that would be required.

The construction facilities would be necessary for handling fuel and doing the fueling operations that would be necessary on the ship—those types of things. And then the second piece is, and probably the harder piece other than just kind of the brick-and-mortar type, is building the structures, the organizations in place to do that work, for instance, nuclear testing, specialized nuclear engineering, nuclear production work. If you look, for instance, at Northrop Grumman Newport News, right now, just to give you a perspective of the people you are talking about in those departments, it is on the order of 769 people in nuclear engineering; 308 people in the major lines of control department; 225 in nuclear quality assurance; and then almost 2,500 people who do nuclear production work. So all of those would have to be, you would have to find that workforce, certify and qualify them, to be able to do that.<sup>29</sup>

The director of NR testified that NGNN and GD/BIW “have sufficient capacity to accommodate nuclear-powered surface ship construction, and therefore there is no need to make the substantial investment in time and dollars necessary to generate additional excess capacity.”<sup>30</sup> In light of this,

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<sup>29</sup> Spoken testimony of Admiral Kirkland Donald before the Seapower and Expeditionary Forces Subcommittee of the House Armed Services Committee, March 1, 2007.

<sup>30</sup> Statement of Admiral Kirkland H. Donald, U.S. Navy, Director, Naval Nuclear Propulsion Program, Before the House Armed Services Committee Seapower and Expeditionary Forces Subcommittee on Nuclear Propulsion For Surface Ships, 1 March 2007, p. 13.

the Navy testified, only the first and third options above are “viable.”<sup>31</sup> The director of NR testified that:

my view of this is we have some additional capacity at both Electric Boat and at Northrop Grumman Newport News. My primary concern is if we are serious about building another nuclear-powered warship, a new class of warship, cost is obviously going to be some degree of concern, and certainly this additional costs, which would be—and I don’t have a number to give you right now, but I think you can see it would be substantial to do it even if you could. It probably doesn’t help our case to move down the path toward building another nuclear-powered case, when we have the capability existing already in those existing yards.<sup>32</sup>

With regard to the third option of building the nuclear portions of the ships at NGNN and/or GD/EB, and the non-nuclear portions at NGSS and/or GD/BIW, the Navy testified that the “Location of final ship erection would require additional analysis.” One Navy official, however, expressed a potential preference for performing final assembly, integration, and test work at NGNN or GD/EB, stating that:

we are building warships in modular sections now. So if we were going to [ask], “Could you assemble this [ship], could you build modules of this ship in different yards and put it together in a nuclear-certified yard?”, the answer is yes, definitely, and we do that today with the Virginia Class [submarine program]. As you know, we are barging modules of [that type of] submarine up and down the coast.

What I would want is, and sort of following along with what [NR director] Admiral [Kirkland] Donald said, you would want the delivering yard to be the yard where the reactor plant was built, tooled, and tested, because they have the expertise to run through all of that nuclear work and test and certify the ship and take it out on sea trials.

But the modules of the non-reactor plant, which is the rest of the ship, could be built theoretically at other yards and barged or transported in other fashion to the delivering shipyard. If I had to do it ideally, that is where I would probably start talking to my industry partners, because although we have six [large] shipyards [for building large navy ships], it is really two corporations [that own them], and those two corporations each own what is now a surface combatant shipyard and they each own a nuclear-capable shipyard. I would say if we were going to go do this, we would sit down with them and say, you know, from a corporation standpoint, what would be the best work flow? What would be the best place to construct modules? And how would you do the final assembly and testing of a nuclear-powered warship?<sup>33</sup>

## **Nuclear-Propulsion Component Manufacturers**

A related issue that Congress may consider in weighing whether the CG(X) or other future Navy surface ships should be nuclear-powered is whether there is sufficient capacity at the firms that make nuclear-propulsion components to accommodate the increase in production volume that

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<sup>31</sup> Source: Statement of The Honorable Dr. Delores M. Etter, Assistant Secretary of the Navy (Research, Development and Acquisition), et al., Before the Seapower and Expeditionary Forces Subcommittee of the House Armed Services Committee on Integrated Nuclear Power Systems for Future Naval Surface Combatants, March 1, 2007, p. 7.

<sup>32</sup> Spoken testimony of Admiral Kirkland Donald before the Seapower and Expeditionary Forces Subcommittee of the House Armed Services Committee, March 1, 2007.

<sup>33</sup> Spoken testimony of Vice Admiral Paul E. Sullivan, Commander, Naval Sea Systems Command, to the Seapower and Expeditionary Forces Subcommittee of the House Armed Services Committee, March 1, 2007.

would result from building the CG(X) or other future Navy surface ships with nuclear power. On this question, the Navy has testified:

Right now, as I look across the industrial base that provides [for nuclear-powered ships], let's just talk about the components, for instance, and I just look across that base, because we have been asserting earlier that we were going to go to [a procurement rate of two Virginia-class submarines per year] earlier [than the currently planned year of FY2012], we had facilitated and have sustained an over-capacity in those facilities to support construction of those additional components. So right now, it depends on the vendor and which one is doing what, the capacity is running right now at probably about 65 percent of what it could be doing, on the order of that. Again, it varies depending on the vendor specifically.

So there is additional capacity in there, and even with the addition of a second Virginia-class submarine, there is still a margin in there, if you are talking about a single cruiser in the early phases of design, we still have margin in there that I believe we can sustain that work in addition to the submarine work within the industrial base.

We would have to look at that in more detail once we determine what the design looks like and the degree to which we can use existing components. If you had to design new components, that would add a little bit more complexity to it, but that is a rough estimate of what I would provide for you now.<sup>34</sup>

## **Ship Maintenance and Repair**

Building CG(X)s or other future Navy surface ships with nuclear power could affect the future distribution of Navy ship maintenance and repair work, because only certain U.S. shipyards are qualified for performing certain kinds of work on nuclear-powered ships. Much of the maintenance and repair work done on nuclear-powered ships is done at the country's four government-operated naval shipyards (NSYs)—Portsmouth NSY at Kittery, ME, Norfolk NSY at Norfolk, VA; Puget Sound NSY at Bremerton, WA; and Pearl Harbor NSY at Pearl Harbor, HI. NGNN and GD/EB also perform some maintenance and repair work on nuclear-powered ships.

## **Crew Training**

Would the Navy have the capacity to train the additional nuclear-qualified sailors that would be needed to crew additional nuclear-powered ships? On this question, the director of NR testified that "My training pipeline does have the capacity without further infrastructure investment to produce the additional personnel required by future classes of [nuclear-powered] ships." He also stated:

We, in looking at the training pipeline, there are a couple of dynamics that are in work right now. First off, the [nuclear-powered aircraft carrier] Enterprise is going to be going away [in 2013], and that is a pretty significant training load just to keep that crew operating.<sup>35</sup> And also, there as the CVN-21 [carrier class] comes on, [that is, as] the Ford-class carriers come on, and the [Nimitz-class nuclear-powered carriers] start to go away, [the number of people

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<sup>34</sup> Spoken testimony of Admiral Kirkland Donald before the Seapower and Expeditionary Forces Subcommittee of the House Armed Services Committee, March 1, 2007.

<sup>35</sup> The Enterprise has a one-of-a-kind, eight-reactor nuclear power plant that creates training demands unique to that ship.

required to crew carriers will decrease, because with the Ford class, we are targeting a 50 percent reduction in the reactor department sizing over there [compared to the Nimitz class].

So for the foreseeable future, the training infrastructure that we have right now will meet the needs to sustain this [additional] class [of nuclear-powered ship], if you choose to do it.<sup>36</sup>

## **Port Calls and Forward Homeporting**

A nuclear-powered ship might be less welcome than a conventionally powered ship in the ports of countries with strong anti-nuclear sentiments. The Navy works to minimize this issue in connection with its nuclear-powered submarines and aircraft carriers, and states that “U.S. nuclear-powered warships are welcome today in over 150 ports in more than 50 countries worldwide, thus allowing our warships to carry out their mission without constraint.”<sup>37</sup>

Some Navy ships are forward-homeported, meaning that they are homeported in foreign countries that are close to potential U.S. Navy operating areas overseas. Forward-homeported Navy ships have occasional need for access to maintenance facilities near their home ports, and foreign shipyards are not qualified to perform certain kinds of maintenance work on nuclear-powered Navy ships. Building CG(X)s or other future Navy surface ships with nuclear power might thus affect the number of potentially suitable locations for forward-homeporting the ships, should the Navy decide that forward homeporting them would be desirable for purposes of shortening transit times to and from potential operating areas.

## **Environmental Impact**

Conventionally powered ships exhaust greenhouse gases and other pollutants that are created through combustion of petroleum-based fuel. They can also leak fuel into the water, particularly if they are damaged in an accident (such as a collision) or by enemy attack. Other environmental impacts of conventionally powered ships include those associated with extracting oil from the ground, transporting it to a refinery, refining it into fuel, and transporting that fuel to the ship. Most of these activities produce additional greenhouse gases and other pollutants.

Nuclear-powered ships do not exhaust greenhouse gases and other pollutants created through conventional combustion. The environmental impacts of nuclear-powered ships include those associated with mining and processing uranium to fuel reactors, and with storing and disposing of spent nuclear fuel cores, radioactive waste water from reactors, and the reactors and other radioactive components of retired nuclear-powered ships. As mentioned in the “Background” section, NR has established a reputation for maintaining very high safety standards for engineering and operating Navy nuclear power plants. In addition, Navy combat ships are built to withstand significant shock and battle damage. It is possible, however, that a very serious accident involving a nuclear-powered Navy ship (such as a major collision) or a major enemy attack on a nuclear-powered Navy ship might damage the ship’s hull and reactor compartment enough to cause a release of radioactivity, which may have adverse effects on the environment.

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<sup>36</sup> Spoken testimony of Admiral Kirkland Donald before the Seapower and Expeditionary Forces Subcommittee of the House Armed Services Committee, March 1, 2007.

<sup>37</sup> Spoken testimony of Admiral Kirkland Donald before the Seapower and Expeditionary Forces Subcommittee of the House Armed Services Committee, March 1, 2007.

## Potential Options for Congress

Potential options for Congress regarding the issue of whether the CG(X) or other future Navy surface ships should be nuclear-powered include but are not limited to the following, some of which might be combined:

- for the CG(X) or other future Navy surface ships, direct the Navy to provide Congress with acquisition plans (including annual funding requirements) for both conventionally powered and nuclear-powered versions, so that Congress can assess both plans;
- to equalize the treatment of petroleum-based and nuclear fuel in Navy ship procurement costs, direct the Navy to exclude the cost of initial fuel cores for nuclear-powered ships from the total procurement cost of those ships, and to fund the procurement of those cores through an appropriation account other than the Shipbuilding and Conversion, Navy (SCN) account;
- direct the Navy to build the CG(X) as a nuclear-powered ship;
- provide initial research and development funding to start work on adapting the design of the Ford-class aircraft carrier nuclear power plant for use in the CG(X); and
- direct the Navy to study the option of, or begin the process of, certifying NGSS and/or GD/BIW to build nuclear-powered ships.

## Legislative Activity for FY2010

### FY2010 Defense Authorization Bill (H.R. 2647/S. 1390)

#### House

The House Armed Services Committee, in its report (H.Rept. 111-166 of June 18, 2009) on H.R. 2647, states:

The committee believes that the next generation [CG(X)] cruiser must meet the challenge of emerging ballistic missile technology and that an integrated nuclear power system is required to achieve maximum capability of the vessel. (Page 72)

The report also states:

The committee remains committed to the direction of section 1012 of the National Defense Authorization Act for Fiscal Year 2008 (Public Law 110-181), which requires the use of an integrated nuclear propulsion system for the CGN(X) [cruiser]. (Page 75)

Section 246 of H.R. 2647 would require DOD to submit to the congressional defense committees a study on the use of thorium-liquid fueled nuclear reactors for Navy surface ships. The text of Section 246 is as follows:

SEC. 246. STUDY ON THORIUM-LIQUID FUELED REACTORS FOR NAVAL FORCES.

(a) Study Required- The Secretary of Defense and the Chairman of the Joint Chiefs of Staff shall jointly carry out a study on the use of thorium-liquid fueled nuclear reactors for naval power needs pursuant to section 1012, of the National Defense Authorization Act for Fiscal Year 2008 (P.L. 110-181; 122 Stat. 303).

(b) Contents of Study- In carrying out the study required under subsection (a), the Secretary of Defense and the Chairman of the Joint Chiefs of Staff shall, with respect to naval power requirements for the Navy strike and amphibious force—

(1) compare and contrast thorium-liquid fueled reactor concept to the 2005 Quick Look, 2006 Navy Alternative Propulsion Study, and the navy CG(X) Analysis of Alternatives study;

(2) identify the benefits to naval operations which thorium-liquid fueled nuclear reactors or uranium reactors would provide to major surface combatants compared to conventionally fueled ships, including such benefits with respect to—

(A) fuel cycle, from mining to waste disposal;

(B) security of fuel supply;

(C) power needs for advanced weapons and sensors;

(D) safety of operation, waste handling and disposal, and proliferation issues compared to uranium reactors;

(E) no requirement to refuel and reduced logistics;

(F) ship upgrades and retrofitting;

(G) reduced manning;

(H) global range at flank speed, greater forward presence, and extended combat operations;

(I) power for advanced sensors and weapons, including electromagnetic guns and lasers;

(J) survivability due to increased performance and reduced signatures;

(K) high power density propulsion;

(L) operational tempo;

(M) operational effectiveness; and

(N) estimated cost-effectiveness; and

(3) conduct a ROM cost-effectiveness comparison of nuclear reactors in use by the Navy as of the date of the enactment of this Act, thorium-liquid fueled reactors, and conventional fueled major surface combatants, which shall include a comparison of—

(A) security, safety, and infrastructure costs of fuel supplies;

(B) nuclear proliferation issues;

(C) reactor safety;

(D) nuclear fuel safety, waste handling, and storage;

(E) power requirements and distribution for sensors, weapons, and propulsion; and

(F) capabilities to fully execute the Navy Maritime Strategic Concept.

(c) Report- Not later than February 1, 2011, the Secretary of Defense and the Chairman of the Joint Chiefs of Staff shall jointly submit to the congressional defense committees a report on the results of the study required under subsection (a).

## **Senate**

Section 1012 of S. 1390 as reported by the Senate Armed Services Committee (S.Rept. 111-35 of July 2, 2009) would repeal Section 1012 of the FY2008 defense authorization act (H.R. 4986/P.L. 110-181 of January 28, 2008). The committee's report states:

The committee recommends a provision [Section 1012] that would repeal section 1012 of the National Defense Authorization Act for Fiscal Year 2008 (P.L. 110-181).

Section 1012 of the National Defense Authorization Act for Fiscal Year 2008 (P.L. 110-181), as amended by section 1015 of the Duncan Hunter National Defense Authorization Act for Fiscal Year 2009 (P.L. 110-417), would require that all new classes of surface combatants and all new amphibious assault ships larger than 15,000 deadweight ton light ship displacement have integrated nuclear power systems, unless the Secretary of Defense determines that the inclusion of an integrated nuclear power system in such vessel is not in the national interest.

The committee believes that the Navy is already having too much difficulty in achieving the goal of a 313-ship fleet without adding a substantial increment to the acquisition price of a significant portion of the fleet. Moreover, current acquisition law and the Weapon System Acquisition Reform Act of 2009 (P.L. 111-23) emphasize the need to start acquisition programs on a sure footing as a central mechanism by which the Department of Defense (DOD) can get control of cost growth and schedule slippage on major defense acquisition programs. Therefore, Congress should be loathe to dictate a particular outcome of a requirements process before the Department has conducted the normal requirements review.

The committee expects that the Navy will continue to evaluate the integrated nuclear power alternative for any new class of major surface combatants, but would prefer that any Navy requirements analysis not be skewed toward a particular outcome. (Page 170)

## Appendix. Prior-Year Legislative Activity

### FY2009 Defense Authorization Bill (H.R. 5658/S. 3001)

#### House

The House-reported version of H.R. 5658 contains a provision (Section 1013) that would amend Section 1012 of the FY2008 defense authorization act (see discussion below) to include amphibious ships and amphibious command ships of a certain minimum size as among the types of ships to be built in the future with nuclear power unless the Secretary of Defense notifies Congress that nuclear power for a given class of ship would not be in the national interest. Section 1013 states:

SEC. 1013. POLICY RELATING TO MAJOR COMBATANT VESSELS OF THE STRIKE FORCES OF THE UNITED STATES NAVY.

Section 1012(c)(1) of the National Defense Authorization Act for Fiscal Year 2008 (P.L. 110-181) is amended by adding at the end the following:

“(D) Amphibious assault ships, including dock landing ships (LSD), amphibious transport-dock ships (LPD), helicopter assault ships (LHA/LHD), and amphibious command ships (LCC), if such vessels exceed 15,000 dead weight ton light ship displacement.”<sup>38</sup>

In its report (H.Rept. 110-652 of May 16, 2008) on H.R. 5658, the House Armed Services Committee stated:

This section would amend section 1012 of the National Defense Authorization Act for Fiscal Year 2008 (P.L. 110-181) by requiring that in addition to future ship classes of aircraft carriers, major surface combatants, and submarines, that assault echelon amphibious ships also must be constructed with integrated nuclear power systems if the ship’s light weight displacement is greater than 15 thousand tons.<sup>39</sup>

The committee believes the future naval force should not be reliant on the availability of fossil fuel for fleet operations. Removing the need for access to fossil fuel sources significantly multiplies the effectiveness of the entire battle force and eliminates the dependence on foreign nation support of deployed naval forces. (Pages 428-429)

#### Senate

The report of the Senate Armed Services Committee on S. 3001 (S.Rept. 110-335 of May 12, 2008) states, with regard to the CG(X) cruiser, that:

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<sup>38</sup> The sizes of commercial ships are often expressed in deadweight tons, while the sizes of Navy combatant ships are usually expressed in terms of full load or light ship displacement. The terms deadweight tons and light ship displacement are not normally joined together to form a single expression of a ship’s size. When joined together, the two terms can be viewed as being in tension with one another, since the first refers to the weight of a ship’s cargo, fuel, water, stores, and other loads, while the second refers to the weight of a ship without these loads.

<sup>39</sup> This report language, which refers to light weight displacement but not to deadweight tons, suggests that the inclusion of the words “dead weight ton” in the Section 1013 might be a printing error.

The John Warner National Defense Authorization Act for Fiscal Year 2007 (P.L. 109-364) required that the Navy include nuclear power in its Analysis of Alternatives (AoA) for the CG(X) propulsion system.

Section 1012 of the National Defense Authorization Act for Fiscal Year 2008 (P.L. 110-181) further requires that CG(X) be nuclear powered, unless the Secretary of Defense submits a notification that inclusion of an integrated nuclear power system is not in the national interest. The statement of managers accompanying that act directed the Secretary of the Navy to submit a report with the budget request for fiscal year 2009 providing information regarding CG(X) design, cost, schedule, industrial base considerations, and risk assessment; that would reflect the results of the CG(X) AoA and provide evidence that the Navy is on schedule for procuring the first ship of the class in 2011.

The Secretary of the Navy has delayed submission of the CG(X) report because the CG(X) AoA, which was scheduled to be complete by third quarter fiscal year 2007, remains under review by the Navy. Fundamental considerations regarding the cruiser's requirements, characteristics, technology readiness levels, and affordability continue to be studied, making it likely that milestone A, which was targeted for September 2007, will slip into 2009. By all measures, there is no reasonable path for the next-generation cruiser to meet the current schedule for milestone B and award of a ship construction contract in 2011.

Pending completion of the AoA, determination of radar requirements, ship characteristics, propulsion system, and an executable program schedule, and in view of the delay to program major milestones, the activities planned for fiscal years 2008 and 2009 cannot be executed per the schedule reflected in the fiscal year 2009 budget request. Therefore, the committee recommends a decrease [in the Navy's request for FY2009 research and development funding] of \$87.2 million in PE 64300N and a decrease of \$33.6 million in PE 64501N. These recommended decreases would maintain the cruiser development activities at the same level as was funded in fiscal year 2008. (Page 195)

## **Compromise**

In lieu of a conference report, there was a compromise version of S. 3001 that was accompanied by a joint explanatory statement. Section 4 of S. 3001 states that the joint explanatory statement "shall have the same effect with respect to the implementation of this Act as if it were a joint explanatory statement of a committee of conference."

Section 1015 of S. 3001 amends Section 1012 of the FY2008 defense authorization act (see discussion below) to include amphibious ships and amphibious command ships of a certain minimum size as among the types of ships to be built in the future with nuclear power unless the Secretary of Defense notifies Congress that nuclear power for a given class of ship would not be in the national interest. Section 1015 states:

SEC. 1015. POLICY RELATING TO MAJOR COMBATANT VESSELS OF THE STRIKE FORCES OF THE UNITED STATES NAVY.

Section 1012(c)(1) of the National Defense Authorization Act for Fiscal Year 2008 (P.L. 110-181) is amended by adding at the end the following:

“(D) Amphibious assault ships, including dock landing ships (LSD), amphibious transport—dock ships (LPD), helicopter assault ships (LHA/LHD), and amphibious command ships (LCC), if such vessels exceed 15,000 dead weight ton light ship displacement.”<sup>40</sup>

## **FY2009 Defense Appropriations Act (H.R. 2638/P.L. 110-329)**

### **House**

The House Appropriations Committee did not file a report on the FY2009 defense appropriations bill. On July 30, 2008, Representative John Murtha, the chairman of the Defense subcommittee of the House Appropriations Committee, issued a press release summarizing the subcommittee’s markup of the bill that same day.<sup>41</sup> The press release does not mention the issue of nuclear power for Navy surface ships.

### **Senate**

The Senate Appropriations Committee did not file a report on the FY2009 defense appropriations bill. On September 10, 2008, the committee issued a press release summarizing the markup of the bill that day by its Defense subcommittee.<sup>42</sup> The press release does not mention the issue of nuclear power for Navy surface ships.

### **Compromise**

In lieu of a conference report, there was a compromise version of the FY2009 defense appropriations bill that was incorporated as Division C of H.R. 2638/P.L. 110-329 of September 30, 2008. (H.R. 2638, the FY2009 Department of Homeland Security appropriations bill, was amended to become a consolidated appropriations bill that includes, among other things, the FY2009 defense appropriations bill.) The compromise version of H.R. 2638 was accompanied by an explanatory statement. H.R. 2638 provides procurement and advance procurement funding for nuclear-powered aircraft carriers, and the joint explanatory statement contains report language relating to electric propulsion technology for surface combatants, but H.R. 2638 and the accompanying explanatory statement do not contain bill or report language relating directly to the issue of nuclear power for Navy surface ships other than aircraft carriers.

## **FY2008 Defense Authorization Act (H.R. 4986/P.L. 110-181)**

### **House**

The House-reported version of the FY2008 defense authorization bill (originally H.R. 1585, a bill that was succeeded by H.R. 4986 following a presidential veto of H.R. 1585 ) contained a

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<sup>40</sup> The inclusion of the words “dead weight ton” in this section might be a printing error; see the previous two footnotes for a discussion.

<sup>41</sup> July 30, 2008, press release from The Honorable John P. Murtha, entitled “Murtha Summary of the FY09 Defense Appropriations Bill.”

<sup>42</sup> September 10, 2008, press release from Senate Appropriations Committee, entitled “Senate Defense Appropriations Subcommittee Approves Fiscal Year 2009 Defense Appropriations Bill.”

provision (Section 1012) that would make it U.S. policy to build submarines, aircraft carriers, cruisers, and other large surface combatants with nuclear power unless the Secretary of Defense notifies Congress that nuclear power for a given class of ship would not be in the national interest. The provision stated:

SEC. 1012. POLICY RELATING TO MAJOR COMBATANT VESSELS OF THE STRIKE FORCES OF THE UNITED STATES NAVY.

(a) Integrated Nuclear Power Systems- It is the policy of the United States to construct the major combatant vessels of the strike forces of the United States Navy, including all new classes of such vessels, with integrated nuclear power systems.

(b) Requirement to Request Nuclear Vessels- If a request is submitted to Congress in the budget for a fiscal year for construction of a new class of major combatant vessel for the strike forces of the United States, the request shall be for such a vessel with an integrated nuclear power system, unless the Secretary of Defense submits with the request a notification to Congress that the inclusion of an integrated nuclear power system in such vessel is not in the national interest.

(c) Definitions- In this section:

(1) MAJOR COMBATANT VESSELS OF THE STRIKE FORCES OF THE UNITED STATES NAVY- The term `major combatant vessels of the strike forces of the United States Navy' means the following:

(A) Submarines.

(B) Aircraft carriers.

(C) Cruisers, battleships, or other large surface combatants whose primary mission includes protection of carrier strike groups, expeditionary strike groups, and vessels comprising a sea base.

(2) INTEGRATED NUCLEAR POWER SYSTEM- The term `integrated nuclear power system' means a ship engineering system that uses a naval nuclear reactor as its energy source and generates sufficient electric energy to provide power to the ship's electrical loads, including its combat systems and propulsion motors.

(3) BUDGET- The term `budget' means the budget that is submitted to Congress by the President under section 1105(a) of title 31, United States Code.

The House Armed Services Committee, in its report (H.Rept. 110-146 of May 11, 2007) on H.R. 1585, stated the following in regard to Section 1012:

This section would require that all new ship classes of submarines, cruisers, and aircraft carriers be built with nuclear power systems unless the Secretary of Defense notifies the committee that it is not in the national interest to do so.

The committee believes that the mobility, endurance, and electric power generation capability of nuclear powered warships is essential to the next generation of Navy cruisers. The Navy's report to Congress on alternative propulsion methods for surface combatants and amphibious warfare ships, required by section 130 of the National Defense Authorization Act for Fiscal Year 2006 (P.L. 109-163), indicated that the total lifecycle cost for medium-sized nuclear surface combatants is equivalent to conventionally powered ships. The

committee notes that this study only compared acquisition and maintenance costs and did not analyze the increased speed and endurance capability of nuclear powered vessels.

The committee believes that the primary escort vessels for the Navy's fleet of aircraft carriers should have the same speed and endurance capability as the aircraft carrier. The committee also notes that surface combatants with nuclear propulsion systems would be more capable during independent operations because there would be no need for underway fuel replenishment. (Page 387)

## **Senate**

The Senate-reported version of the FY2008 defense authorization bill (S. 1547) did not contain a provision analogous to Section 1012 of the House-reported version of H.R. 1585. The report of the Senate Armed Services Committee on S. 1547 (S.Rept. 110-77 of June 5, 2007) did not comment directly on the issue of nuclear power for Navy ships other than submarines and aircraft carriers.

## **Conference**

Section 1012 of the conference report (H.Rept. 110-477 of December 6, 2007) on H.R. 1585 is the same as Section 1012 of the House-reported version of H.R. 1585 (see discussion above). In discussing Section 1012, the conference report stated:

The Navy's next opportunity to apply this guidance will be the next generation cruiser, or "CG(X)". Under the current future-years defense program (FYDP), the Navy plans to award the construction contract for CG(X) in fiscal year 2011. Under this provision, the next cruiser would be identified as "CGN(X)" to designate the ship as nuclear powered. Under the Navy's normal shipbuilding schedule for the two programs that already have nuclear power systems (aircraft carriers and submarines), the Navy seeks authorization and appropriations for long lead time nuclear components for ships 2 years prior to full authorization and appropriation for construction.

The conferees recognize that the milestone decision for the Navy's CG(X) is only months away. After that milestone decision, the Navy and its contractors will begin a significant design effort, and, in that process, will be making significant tradeoff decisions and discarding major options (such as propulsion alternatives). This is the normal process for the Navy and the Department of Defense (DOD) to make choices that will lead to producing a contract design that will be the basis for awarding the construction contract for the lead ship in 2011.

In order for the Navy to live by the spirit of this guidance, the conferees agree that:

- (1) the Navy would be required to proceed through the contract design phase of the program with a comprehensive effort to design a CGN(X) independent of the outcome of decisions that the Navy or the DOD will make at the next milestone decision point regarding any preferred propulsion system for the next generation cruiser;
- (2) if the Navy intends to maintain the schedule in the current FYDP and award a vessel in fiscal year 2011, the Navy would need to request advance procurement for nuclear components in the fiscal year 2009 budget request; and
- (3) the Navy must consider options for:

- (a) maintaining the segment of the industrial base that currently produces the conventionally powered destroyer and amphibious forces of the Navy;
- (b) certifying yards which comprise that segment of the industrial base to build nuclear-powered vessels; or
- (c) seeking other alternatives for building non-nuclear ships in the future if the Navy is only building nuclear-powered surface combatant ships for some period of time as it builds CGN(X) vessels; and
- (d) identifying sources of funds to pay for the additional near-term costs of the integrated nuclear power system, either from offsets within the Navy's budget, from elsewhere within the Department's resources, or from gaining additional funds for DOD overall.

The conferees recognize that these considerations will require significant additional near-term investment by the Navy. Some in the Navy have asserted that, despite such added investment, the Navy would not be ready to award a shipbuilding contract for a CGN(X) in fiscal year 2011 as in the current FYDP.

Section 128 of the John Warner National Defense Authorization Act for Fiscal Year 2007 (Public Law 109—364) required that the Navy include nuclear power in its Analysis of Alternatives (AOA) for the CG(X) propulsion system. The conferees are aware that the CG(X) AOA is nearing completion, in which case the Navy should have some indications of what it will require to design and construct a CGN(X) class.

Accordingly, the conferees direct the Secretary of the Navy to submit a report to the congressional defense committees with the budget request for fiscal year 2009 providing the following information:

- (1) the set of next generation cruiser characteristics, such as displacement and manning, which would be affected by the requirement for including an integrated nuclear power system;
- (2) the Navy's estimate for additional costs to develop, design, and construct a CGN(X) to fill the requirement for the next generation cruiser, and the optimal phasing of those costs in order to deliver CGN(X) most affordably;
- (3) the Navy's assessment of any effects on the delivery schedule for the first ship of the next generation cruiser class that would be associated with shifting the design to incorporate an integrated nuclear propulsion system, options for reducing or eliminating those schedule effects, and alternatives for meeting next generation cruiser requirements during any intervening period if the cruiser's full operational capability were delayed;
- (4) the Navy's estimate for the cost associated with certifying those shipyards that currently produce conventionally powered surface combatants, to be capable of constructing and integrating a nuclear-powered combatant;
- (5) any other potential effects on the Navy's 30-year shipbuilding plan as a result of implementing these factors;
- (6) such other considerations that would need to be addressed in parallel with design and construction of a CGN(X) class, including any unique test and training facilities, facilities and infrastructure requirements for potential CGN(X) homeports, and environmental assessments that may require long-term coordination and planning; and

(7) an assessment of the highest risk areas associated with meeting this requirement, and the Navy's alternatives for mitigating such risk. (Pages 984-986)

H.R. 1585 was vetoed by the President on December 28, 2007. In response, Congress passed a modified bill, H.R. 4986, that took into account the President's objections to H.R. 1585. The modifications incorporated into H.R. 4986 did not affect the provisions discussed here, and for these and other unmodified parts of the bill, H.Rept. 110-477 in effect serves as the conference report for H.R. 4986. H.R. 4986 was signed into law as P.L. 110-181 on January 28, 2008.

Section 1012 of the conference report is similar in some respects to the so-called Title VIII legislation of the 1970s that required future Navy ships of certain kinds to be nuclear-powered.<sup>43</sup>

## **FY2006 Defense Authorization Act (H.R. 1815/P.L. 109-163)**

Section 130 of the conference report (H.Rept. 109-360 of December 18, 2005) on the FY2006 defense authorization act (H.R. 1815, P.L. 109-163 of January 6, 2006) required the Navy to submit a report by November 1, 2006, on alternative propulsion methods for surface combatants and amphibious warfare ships. The Navy submitted the report to Congress in January 2007. Section 130 states:

**SEC. 130. REPORT ON ALTERNATIVE PROPULSION METHODS FOR SURFACE COMBATANTS AND AMPHIBIOUS WARFARE SHIPS.**

(a) ANALYSIS OF ALTERNATIVES.—The Secretary of the Navy shall conduct an analysis of alternative propulsion methods for surface combatant vessels and amphibious warfare ships of the Navy.

(b) REPORT.—The Secretary shall submit to the congressional defense committees a report on the analysis of alternative propulsion systems carried out under subsection (a). The report shall be submitted not later than November 1, 2006.

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<sup>43</sup> The Title VIII legislation comprised Sections 801-804 of the FY1975 defense authorization act (H.R. 14592/P.L. 93-365, August 5, 1974, 88 Stat. 408-409). The legislation was codified at 10 USC 7291. Section 801 made it U.S. policy "to modernize the strike forces of the United States Navy by the construction of nuclear-powered major combatant vessels and to provide for an adequate industrial base for the research, development, design, construction, operation, and maintenance for such vessels." Section 801 also stated: "New construction major combatant vessels for the strike forces of the United States Navy authorized subsequent to the date of enactment of this Act becomes law [sic] shall be nuclear powered, except as provided in this title." Section 802 defined the term "major combatant vessels for the strike forces of the United States Navy." Section 803 required the Secretary of Defense to submit a report to Congress each year, along with the annual budget request, on the application of nuclear power to such ships. Section 804 stated that "All requests for authorizations or appropriations from Congress" for such ships shall be for construction of nuclear-powered versions of such ships "unless and until the President has fully advised the Congress that construction of nuclear powered vessels for such purpose is not in the national interest," in which case the President is to provide, for Congress' consideration, an alternate program of nuclear-powered ships, with appropriate design, cost, and schedule information.

Title VIII was repealed by Section 810 of the FY1979 defense authorization act (S. 3486/P.L. 95-485, October 20, 1978, 92 Stat. 1623). Section 810 of that act replaced the Title VIII legislation with a policy statement on Navy shipbuilding policy that did not mandate the use of nuclear power for any Navy ships. Section 810, like the Title VIII legislation, was codified at 10 USC 7291. It was subsequently recodified at 10 USC 7310, pursuant to a law (H.R. 4623/P.L. 97-295 of October 12, 1982) that amended titles 10, 14, 37, and 38 to codify recent law. 10 USC 7310 was then repealed by Section 824(a)(8) of the FY1994 defense authorization act (H.R. 2401/P.L. 103-160 of November 30, 1993).

(c) **MATTERS TO BE INCLUDED.**—The report under subsection (b) shall include the following:

- (1) The key assumptions used in carrying out the analysis under subsection (a).
  - (2) The methodology and techniques used in conducting the analysis.
  - (3) A description of current and future technology relating to propulsion that has been incorporated in recently-designed surface combatant vessels and amphibious warfare ships or that is expected to be available for those types of vessels within the next 10-to-20 years.
  - (4) A description of each propulsion alternative for surface combatant vessels and amphibious warfare ships that was considered under the study and an analysis and evaluation of each such alternative from an operational and cost-effectiveness standpoint.
  - (5) A comparison of the life-cycle costs of each propulsion alternative.
  - (6) For each nuclear propulsion alternative, an analysis of when that nuclear propulsion alternative becomes cost effective as the price of a barrel of crude oil increases for each type of ship.
  - (7) The conclusions and recommendations of the study, including those conclusions and recommendations that could impact the design of future ships or lead to modifications of existing ships.
  - (8) The Secretary's intended actions, if any, for implementation of the conclusions and recommendations of the study.
- (d) **LIFE-CYCLE COSTS.**—For purposes of this section, the term “life-cycle costs” includes those elements of cost that would be considered for a life-cycle cost analysis for a major defense acquisition program.

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